Dielectric resonator, dielectric filter, dielectric duplexer and communications device

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Abstract

A compact dielectric resonator of high Qu, in which an electrode formed of an oxide superconducting material is provided on a surface of the dielectric so as to serve as an electrode. A dielectric filter, dielectric duplexer, and a communications device, in which the compact resonator is incorporated, are also provided. The dielectric which constitutes the dielectric resonator of the present invention is preferably a Ba(Mg, Ma)O3-based dielectric (wherein Ma is at least one pentavalent elemental metal but cannot be Ta alone), and the oxide superconducting electrode is formed of an oxide superconducting material selected from among a RE-M-Cu-O-based oxide superconducting material (wherein RE is a rare earth element and M is an alkaline earth metal element), a Bi-Sr-Ca-Cu-O-based oxide superconducting material (which encompasses those in which Bi is partially substituted by Pb), and a Tl-Ba-Ca-Cu-O-based oxide superconducting material.

Description

[0001] The present invention relates to a compact dielectric resonator of a very high value of Q, to a dielectric filter making use of the resonator, to a dielectric duplexer, and to a communications device.

Background Art

[0002] Recently, dielectric resonators utilizing a dielectric as a material for constructing a resonator have been widely used so as to miniaturize the resonant system of an electric circuit which handles high-frequency waves such as microwaves. Such dielectric resonators utilize the phenomenon that the wavelength of electromagnetic wave in a dielectric is 1/(epsilon r)<1/2)
<#s> [0003] In resonant systems of the above-mentioned types, Qu (i.e., Q under no-load) varies not only depending on Qd (= 1/tan delta , Q of the dielectric per se) but also on Qc (i.e., Q attributed to a conductor loss which is caused by the current that flows in the surface of metal). Qu is expressed by the following equation: 1/Qu = (1/Qd) + (1/Qc). Therefore, in order to realize a resonant system of a high Qu, it is essential that a dielectric material of high Qd be used, and in addition, it is essential that electrodes of high Qc - in other words, electrodes of small conductor loss - be used.

[0004] Japanese Patent Application Laid-Open (kokai) No. 1-154603 discloses a method for achieving a high Qu (Q under no-load) by forming RE-M-Cu-O-based superconducting electrodes on a dielectric ceramic of any of a variety of types, including $MgTiO_3$-(Ca, Me)TiO_3-based dielectric ceramic, Ba(Zr, Zn, Ta)O_3-based dielectric ceramic, (Zr, Sn)TiO_4, and BaO-PbO-Nd_2O_3-TiO_2-based dielectric ceramic. Also, Japanese Patent Application Laid-Open (kokai) No. 9-298404 discloses a method which utilizes Ba(Mg, Ta)O_3 as a dielectric material.

[0005] FIGs. 6 and 7 are graphs showing temperature-dependent characteristics of tan delta (=1/Qd) at 10 GHz for a variety of dielectric materials. As shown in FIGs. 6 and 7, $MgTiO_3$-(Ca, Me)TiO_3-based material, Ba(Zr, Zn, Ni, Ta)O_3-based material, BaO-PbO-Nd_2O_3-TiO_2-based material, and Ba(Mg, Ta)O_3-based material exhibit disadvantageously poor low-temperature characteristics, because in each case tan delta does not decrease at a constant rate across an entire range of low temperatures.

[0006] In a (Zr, Sn)TiO_4-based dielectric material, tan delta decreases at a constant rate throughout the low temperature range. However, this material has a disadvantage in that violent interface reaction occurs between the resultant dielectric and superconducting electrodes. Particularly when a thick film is formed through screen printing, interfacial reaction between a dielectric and oxide superconducting material raises a critical issue; violent interfacial reaction degrades the superconducting material and therefore no superconducting characteristic can be obtained. Therefore, in order to pursue practical use of various products derived from superconducting materials, there exists a strong need for a new substrate material that does not cause interfacial reaction. MgO is a candidate dielectric material that does not cause interfacial reaction between the dielectric and oxide superconducting material, and thus is suitable for use with high-frequency waves. However, MgO has an epsilon r (relative dielectric constant) of 9-10, which is low as compared to that of the above-mentioned dielectric (epsilon r = 20-30), making MgO disadvantageous in terms of miniaturizing the resonant system.

[0007] Accordingly, a primary object of the present invention is to provide a compact dielectric resonator of high Qu, in which an electrode formed of oxide superconducting material is provided on a surface of the dielectric.

[0008] Another object of the present invention is to provide a dielectric filter making use of such a compact resonator.

[0009] A further object of the present invention is to provide a dielectric duplexer making use of the compact resonator.

[0010] A still further object of the present invention is to provide a communications device making use of the compact resonator.

[0011] In a first aspect of the present invention, there is provided a dielectric resonator comprising a dielectric and an oxide superconducting electrode provided on a surface of the dielectric, wherein the dielectric is a Ba(Mg, Ma)O_3-based dielectric (wherein Ma is at least one pentavalent elemental metal but cannot be Ta

alone), and the oxide superconducting electrode is formed of an oxide superconducting material selected from among a RE-M-Cu-O-based oxide superconducting material (wherein RE is a rare earth element and M is an alkaline earth metal element), a Bi-Sr-Ca-Cu-O-based oxide superconducting material (which encompasses those in which Bi is partially substituted by Pb), and a Tl-Ba-Ca-Cu-O-based oxide superconducting material.

[0012] Preferably, Ma is at least one element selected from among Ta, Sb, and Nb (excepting the case where Ta is used alone).

[0013] In a second aspect of the present invention, there is provided a dielectric resonator comprising a dielectric and an oxide superconducting electrode provided on a surface of the dielectric, wherein the dielectric is a Ba(Mb, Mg, Ta)O3-based dielectric (wherein Mb is a tetravalent or pentavalent elemental metal), and the oxide superconducting electrode is formed of an oxide superconducting material selected from among a RE-M-Cu-O-based oxide superconducting material (wherein RE is a rare earth element and M is an alkaline earth metal element), a Bi-Sr-Ca-Cu-O-based oxide superconducting material (which encompasses those in which Bi is partially substituted by Pb), and a Tl-Ba-Ca-Cu-O-based oxide superconducting material.

[0014] Preferably, Mb is at least one element selected from among Sn, Zr, Sb, and Nb.

[0015] Preferably, the Ba(Mb, Mg, Ta)O3-based dielectric is a Ba(Sn, Mg, Ta)O3-based dielectric. Preferably, the composition of the Ba(Sn, Mg, Ta)O3-based dielectric is Ba(Snx, Mgy, Taz)O7/2-x/2-3y/2 (wherein x+y+z=1, 0.04≤x≤0.26, 0.23≤y≤0.31, and 0.51≤z≤0.65).

[0016] In a dielectric resonator according to the second aspect of the present invention, the Ba(Mb, Mg, Ta)O3-based dielectric may be a Ba(Mg, Sb, Ta)O3-based dielectric. In this case, the composition of the Ba(Mg, Sb, Ta)O3-based dielectric is BaxMgy(Sbv, Ta1-v)zOw (wherein x+y+z=1, w is an arbitrary number, x, y, and z fall within the tetrahedron defined by connecting points A, B, C, and D shown in Table 1, and 0.001≤v≤0.300).
Id=Table 1 Columns=4

Head Col 1:
Head Col 2: x
Head Col 3: y
Head Col 4: z
A 0.495 0.175 0.330
B 0.495 0.170 0.335
C 0.490 0.170 0.340
D 0.490 0.180 0.330

[0017] In the first and second aspects of the present invention, the RE-M-Cu-O-based oxide superconducting material may be YBa2Cu3O7-x, the Bi-Sr-Ca-Cu-O-based oxide superconducting material may be (Bi,Pb)2Sr2Ca2Cu3Ox or Bi2,Sr2CaCu2Ox, and the Tl-Ba-Ca-Cu-O-based oxide superconducting material may be Tl2Ba2Ca2Cu3Ox.

[0018] In a third aspect of the present invention, there is provided a dielectric filter comprising a dielectric resonator according to any of the above aspects of the present invention, and an external connecting means.

[0019] In a fourth aspect of the present invention, there is provided a dielectric duplexer comprising at least two dielectric filters, input-output connection means for each of the dielectric filters, and antenna connecting means which is connected to the dielectric filter, wherein at least one of the dielectric filters is a dielectric filter as claimed in the present invention.

[0020] In a fifth aspect of the present invention, there is provided a communications device comprising a dielectric duplexer as described above, a transmitting circuit which is connected to at least one input-output connection means of the dielectric duplexer, a receiving circuit which is connected to at least one input-output connection means other than that to be connected to the transmitting circuit, and an antenna which is connected to the antenna connecting means of the dielectric duplexer.

[0021] Examples of the RE element that serves as a constituent of the RE-M-Cu-O-based oxide superconducting material include Y La, Ce, Pr, Nd, Pm, Sm, Eu,

Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. M (i.e., an alkaline earth metal element) is preferably Ba or Sr among others.

[0022] Since the surface resistance (Rs) of an oxide superconducting material is lower than that of metal at a temperature lower than a critical temperature (Tc), smaller conductor loss occurs in electrodes, to thereby greatly improve Qc. Also, the dielectric used in the present invention exhibits an excellent tan delta characteristic at a low temperature, and does not cause interfacial reaction with an oxide superconducting material. Therefore, the dielectric of the present invention is suitable for forming an oxide superconducting electrode on the surface thereof.

[0023] The above and other objects, features, and advantages of the present invention will be readily appreciated as the same becomes better understood with reference to the following detailed description of the preferred embodiments when considered in connection with the accompanying drawings, in which:

FIG. 1 is an explanatory sketch showing an example dielectric resonator according to the present invention;
FIG. 2 is a graph showing the low-temperature Qu (Q under no load) characteristics of TE011-mode dielectric resonators;
FIG. 3 is an explanatory sketch showing another example dielectric resonator according to the present invention;
FIG. 4 is a graph showing the low-temperature Qu (Q under no load) characteristics of TE010-mode dielectric resonators;
FIG. 5 is a block diagram showing an example communications device according to the present invention;
FIG. 6 is a graph showing the temperature versus tan delta (at 10 GHz) curves of different dielectrics; and
FIG. 7 is another graph showing the temperature versus tan delta (at 10 GHz) curves of a variety of dielectrics.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0024] FIG. 1 is an explanatory sketch of an example TE011-mode dielectric resonator of the present invention.

[0025] The resonant system of the dielectric resonator 10 uses a both-terminal-short-circuit-type dielectric resonator method (Hakki & Colemann method), which is a method generally employed for evaluation of microwave-band dielectric characteristics of a dielectric material and for measuring surface resistance of a superconductor. The Hakki & Colemann method generally employs a structure in which a dielectric is sandwiched between two metal plates; however, the dielectric resonator 10 shown in FIG. 1 has a structure in which one of the metal plates is substituted by a superconducting electrode formed on the surface of the dielectric. That is, the dielectric resonator 10 shown in FIG. 1 includes a dielectric substrate 12, and a film-shaped superconducting electrode 14 is formed on the surface of the dielectric substrate 12. A copper plate 16 is disposed to face the superconducting electrode 14. A dielectric 18 is sandwiched between the superconducting electrode 14 and the copper plate 16. Further, two excitation cables 20 and 22 are disposed on opposite sides of the dielectric 18 and between the superconducting electrode 14 and the copper plate 16, such that the cables 20 and 22 face each other.

[0026] In the dielectric resonator of FIG. 1, a Ba(Sn, Mg, Ta)O3-based dielectric (size: ϕ8.5 mm x t3.8 mm) is used as a dielectric 18. The composition is Ba (SnxMgyTaz)O7/2-x/2-3y/2 (in which $x + y + z = 1$, $0.04 \le x \le 0.26$, $0.23 \le y \le 0.31$, $0.51 \le z \le 0.65$). The dielectric substrate 12 on which the superconducting electrode 14 is formed was also fabricated from Ba(Sn, Mg, Ta)O3.

[0027] In this dielectric resonator, Bi-Pb-Sr-Ca-Cu-O film or Y-Ba-Cu-O film is used as the superconducting electrode 14. More specifically, for example, (Bi, Pb) 2Sr2Ca2Cu3Ox or YBa2Cu3O7-x is used. The superconducting electrode 14 using one of these materials can be formed, for example, in the following manner.

[0028] A Bi-Pb-Sr-Ca-Cu-O film can be formed by use of the following method. A powder of the composition Bi-Pb-Sr-Ca-Cu-O (2223 phase) and an organic vehicle are mixed, subjected to adjustment of the viscosity thereof, and screen-printed on the dielectric substrate 12. The resultant film is dried at 100 DEG C to 150 DEG C, and the dried film is fired at 840 DEG C to 860 DEG C for 100 to 200 hours in air.

[0029] A Y-Ba-Cu-O film can be formed by use of the following method. A powder of the composition Y-Ba-Cu-O and an organic vehicle are mixed, subjected to adjustment of the viscosity thereof, and screen-printed on the dielectric ceramic. The resultant film is fired at 860 DEG C to 880 DEG C for 5 to 10 hours in an oxygen atmosphere.

[0030] A dielectric resonator 10 having the Bi-Pb-Sr-Ca-Cu-O film serving as the superconducting electrode 14 and a dielectric resonator 10 having the Y-Ba-Cu-O film were formed, and low-temperature Qu was measured. The results are plotted by use of white circles and white triangles in FIG. 2. BPSCCO appearing in FIG. 2 represents Bi-Pb-Sr-Ca-Cu-O, and YBCO therein represents Y-Ba-Cu-O.

[0031] Further, as a first comparative example, there was fabricated a dielectric resonator having the same structure as the dielectric resonator 10 shown in FIG. 1 except that a copper plate was provided in place of the superconducting electrode 14. In other words, the dielectric resonator of the first comparative example has the same structure as the dielectric resonator 10 shown in FIG. 1 except that the dielectric 18 is sandwiched between two copper plates. Low-temperature Qu of the dielectric resonator of the first comparative example was measured, and the results are plotted by use of black rhombuses in FIG. 2.

[0032] As is apparent from FIG. 2 the dielectric resonators 10 can achieve Qu higher than that of the dielectric resonator in the first comparative example in which the dielectric is sandwiched between two copper plates. Namely, the superconducting electrode 14 formed on the dielectric substrate 12 does not undergo interfacial reaction with the dielectric but exhibits superconducting characteristics.

[0033] FIG. 3 is an explanatory sketch of an example TM010-mode dielectric resonator of the present invention. The dielectric resonator 30 shown in FIG. 3 includes a dielectric substrate 32. Film-shaped superconducting electrodes 34 and 36 are formed on the top and bottom surfaces of the dielectric substrate 32, respectively. The dielectric substrate 32 is fixed within a metal casing 40 through the mediation of a Teflon sheet 38. An excitation cable 42 is disposed at one end of the metal casing 40, and an excitation cable 44 is disposed at the other end.

[0034] The dielectric substrate 32 of this resonator 30 was also fabricated from Ba(Sn, Mg, Ta)O3-based dielectric as in the dielectric resonator 10. The superconducting electrodes 34 and 36 were fabricated from Bi-Pb-Sr-Ca-Cu-O film by use of the above-mentioned method. Low-temperature Qu was measured, and the results are plotted by use of white circles in FIG. 4. BPSCCO appearing in FIG. 4 represents Bi-Pb-Sr-Ca-Cu-O.

[0035] Further, as a second comparative example there was fabricated a dielectric resonator having the same structure as the dielectric resonator 30 shown in FIG. 3, except that a copper thin film was formed on the dielectric substrate 32 instead of the superconducting electrodes 34 and 36. In other words, the dielectric resonator of the second comparative example has the same structure as the dielectric resonator 30 shown in FIG. 3 except that the dielectric 32 is sandwiched between two copper thin films. The low-temperature Qu of the dielectric resonator of the second comparative example was measured, and the results are plotted by use of black rhombuses in FIG. 4.

[0036] As is apparent from FIG 4, the dielectric resonators 30 can achieve a Qu higher than that of the dielectric resonator of the second comparative example. Namely, the superconducting electrodes 34 and 36 formed on the top and bottom surfaces of the dielectric substrate 32 do not undergo an interfacial reaction with the dielectric but exhibit superconducting characteristics.

[0037] The case in which Ba(Sn, Mg, Ta)O3-based dielectric was used as a dielectric has been described with reference to embodiment examples and the related data shown in FIGs. 1 through 4; however, when other dielectrics described hereinabove are used, the same effect can be produced. Further, the oxide superconducting material is not limited only to the materials used in the embodiments as described with reference to FIGs. 1 and 3; when other oxide superconducting materials hereinabove are used, the same effect can be produced.

[0038] A TE011-mode dielectric resonator and a TE010-mode dielectric resonator have been described with reference to FIGs. 1 through 4; however, the present invention is not limited to only these types of resonators. The invention can be also applied to other types of dielectric resonators, for example, other TE-mode, TM-mode, TEM-mode dielectric resonators, or resonators in which strip lines are fabricated on the dielectric substrate thereof.

[0039] FIG. 5 is a block diagram of an example communications device using the dielectric resonator of the present invention. The communications device 50 includes a dielectric duplexer 52, a transmitting circuit 54, a receiving circuit 56, and an antenna 58. The transmitting circuit 54 is connected to an input means 60 of the dielectric duplexer 52, and the receiving circuit 56 is connected to an output means 62 of the dielectric duplexer 52. The antenna 58 is connected to an antenna connecting means 64 of the dielectric duplexer 52. The dielectric duplexer 52 includes two dielectric filters 66 and 68. The dielectric filters 66 and 68 each include the dielectric resonator of the present invention and external connecting means connected to the resonator. In this example communications device, the filters are formed by connecting external connecting means 70 to the excitation cables of the dielectric resonators 10 (30); one dielectric filter 66 is connected between the input means 60 and the antenna connecting means 64, and the other dielectric filter 68 is connected between the antenna connecting means 64 and the output means 62.

[0040] As described above, in the dielectric resonator according to the present invention, no interfacial reaction occurs between the dielectric and the superconducting material, to thereby provide an excellent superconduting characteristic, achieving a higher Qu than the case in which metal electrodes are used. Therefore, when such a dielectric resonator of the present invention is incorporated into a dielectric filter, dielectric duplexer, or a communications device, excellent working characteristics can be obtained.

Claims

1. A dielectric resonator comprising a dielectric and an oxide superconducting electrode provided on a surface of the dielectric, wherein the dielectric is a Ba(Mg, Ma)O3-based dielectric (wherein Ma is at least one pentavalent elemental metal but cannot be Ta alone), and the oxide superconducting electrode is formed of an oxide superconducting material selected from among a RE-M-Cu-O-based oxide superconducting material (wherein RE is a rare earth element and M is an alkaline earth metal element), a Bi-Sr-Ca-Cu-O-based oxide superconducting material (which encompasses those in which Bi is partially substituted by Pb), and a Tl-Ba-Ca-Cu-O-based oxide superconducting material.

2. A dielectric resonator comprising a dielectric and an oxide superconducting electrode provided on a surface of the dielectric, wherein the dielectric is a Ba(Mb, Mg, Ta)O3-based dielectric (wherein Mb is a tetravalent or pentavalent elemental metal), and the oxide superconducting electrode is formed of an oxide superconducting material selected from among a RE-M-Cu-O-based oxide superconducting material (wherein RE is a rare earth element and M is an alkaline earth metal element), a Bi-Sr-Ca-Cu-O-based oxide superconducting material (which encompasses those in which Bi is partially substituted by Pb), and a Tl-Ba-Ca-Cu-O-based oxide superconducting material.

3. A dielectric resonator according to Claim 1, wherein said Ma is at least one element selected from among Ta, Sb, and Nb (excepting the case where Ta is used alone).

4. A dielectric resonator according to Claim 2, wherein said Mb is at least one element selected from among Sn, Zr, Sb, and Nb.

5. A dielectric resonator according to Claim 2, wherein said Ba(Mb, Mg, Ta)O3-based dielectric is a Ba(Sn, Mg, Ta)O3-based dielectric.

6. A dielectric resonator according to Claim 5, wherein said Ba(Sn, Mg, Ta)O3-based dielectric has a composition represented by Ba(Snx, Mgy, Taz)O7/2-x/2-3y/2 (wherein x+y+z=1, 0.04≤x≤0.26, 0.23≤y≤0.31, and 0.51≤z≤0.65).

7. A dielectric resonator according to Claim 2, wherein said Ba(Mb, Mg, Ta)O3-based dielectric is a Ba(Mg, Sb, Ta)O3-based dielectric.

8. A dielectric resonator according to Claim 7, wherein said Ba(Mg, Sb, Ta)O3-based dielectric has a composition represented by BaxMgy(Sbv, Ta1-v)zOw (wherein x+y+z=1, w is an arbitrary number, and x, y, and z fall within the tetrahedron defined by connecting points A, B, C, and D:
Columns=4

Head Col 1:
Head Col 2: x
Head Col 3: y
Head Col 4: z
A 0.495 0.175 0.330
B 0.495 0.170 0.335
C 0.490 0.170 0.340
D 0.490 0.180 0.330
and 0.001≤v≤0.300).

9. A dielectric resonator according to any one of Claims 1 through 8, wherein said RE-M-Cu-O-based oxide superconducting material is YBa2Cu3O7-x.

10. A dielectric resonator according to any one of Claims 1 through 8, wherein said Bi-Sr-Ca-Cu-O-based oxide superconducting material may be (Bi,Pb) 2Sr2Ca2Cu3Ox or Bi2,Sr2CaCu2Ox.

11. A dielectric resonator according to any one of Claims 1 through 8, wherein said Tl-Ba-Ca-Cu-O-based oxide superconducting material is Tl2Ba2Ca2Cu3Ox.

12. A dielectric filter comprising a dielectric resonator according to any of Claims 1 through 11 and an external connecting means.

13. A dielectric duplexer comprising at least two dielectric filters, input-output connection means for each of the dielectric filters, and antenna connecting means which is connected to the dielectric filter, wherein at least one of the dielectric filters is a dielectric filter as described in Claim 12.

14. A communications device comprising a dielectric duplexer as described in Claim 13, a transmitting circuit which is connected to at least one input-output connection means of the dielectric duplexer, a receiving circuit which is connected to at least one input-output connection means other than that to be connected to the transmitting circuit, and an antenna which is connected to the antenna connecting means of the dielectric duplexer.

Fig. 1

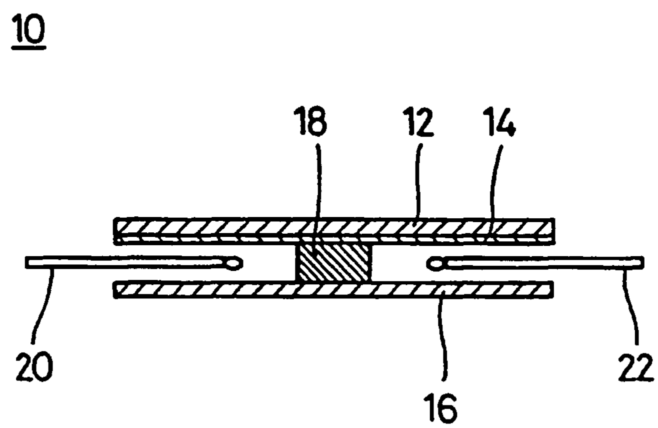


Fig. 2

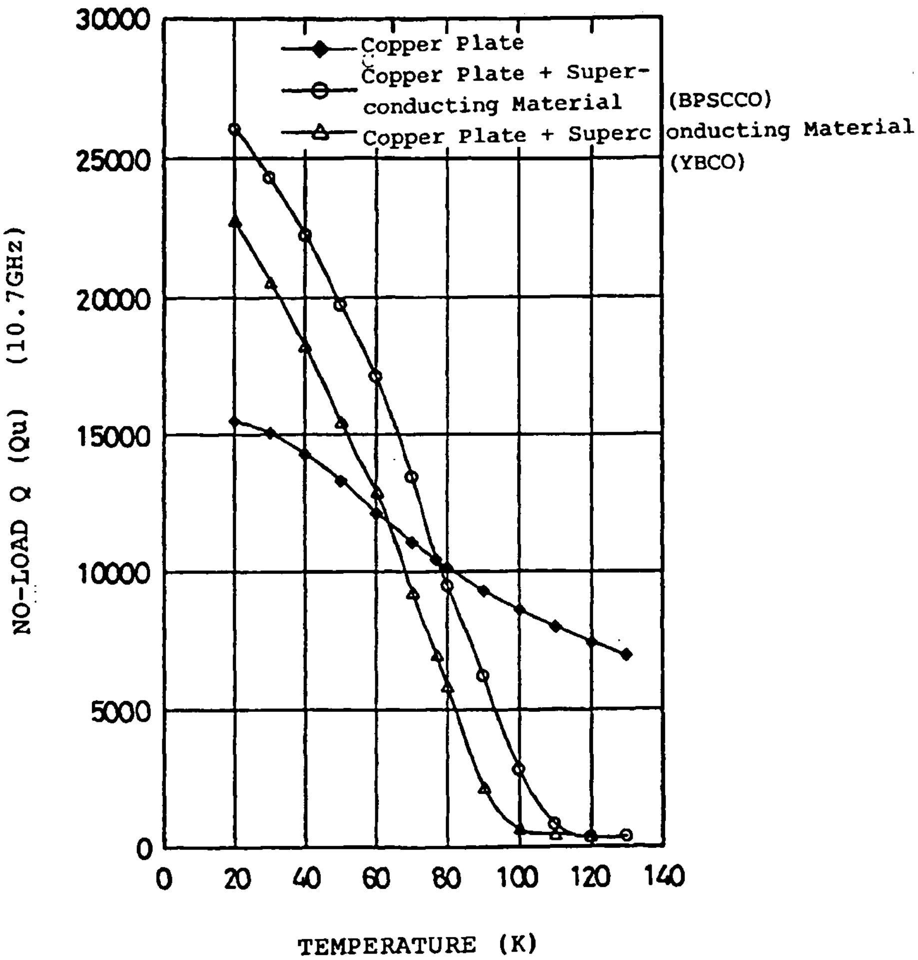

Copper Plate
Copper Plate + Super-conducting Material (BPSCCO)
Copper Plate + Superconducting Material (YBCO)
NO-LOAD Q (Qu) (10.7GHz)
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
120
140
TEMPERATURE (K)

Fig. 3

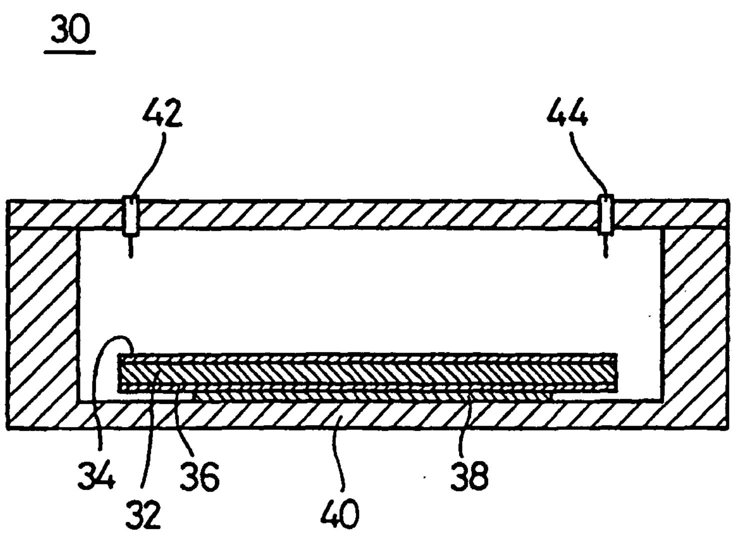
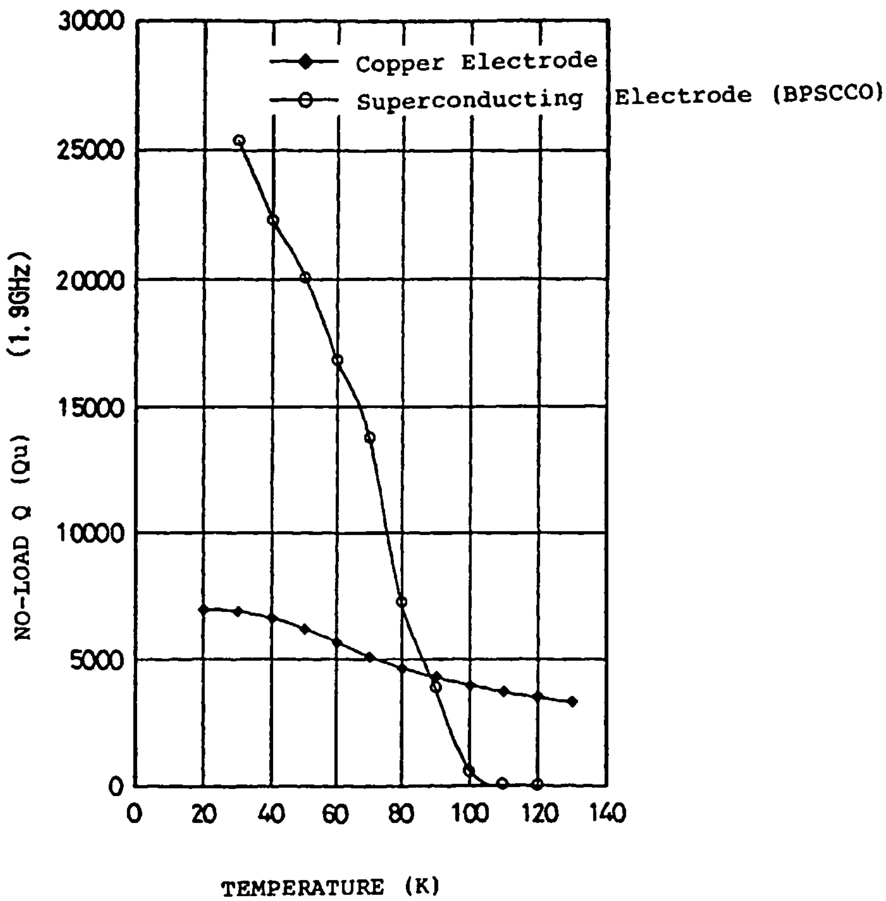


Fig. 4



Copper Electrode
Superconducting Electrode (BPSCCO)
NO-LOAD Q (Qu) (1.9GHz)
TEMPERATURE (K)
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
120
140

Fig. 5

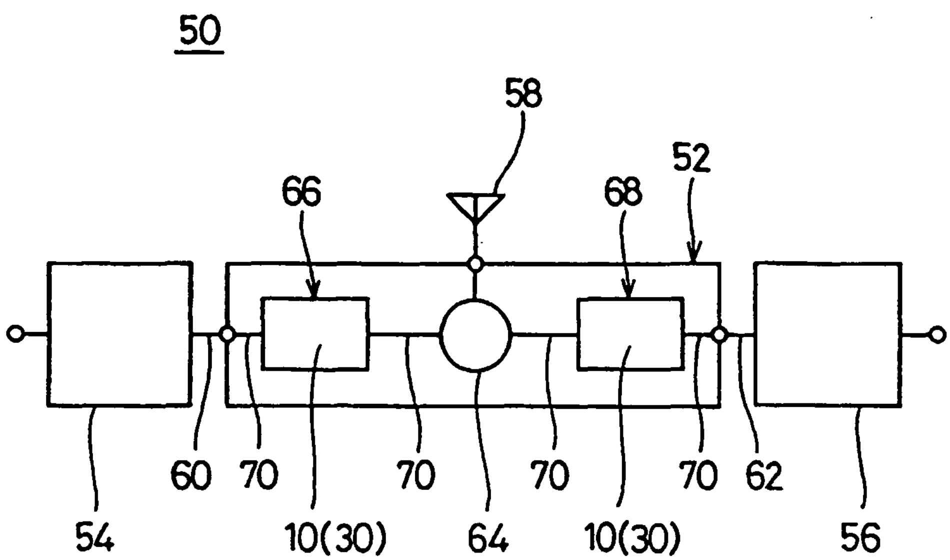


Fig. 6

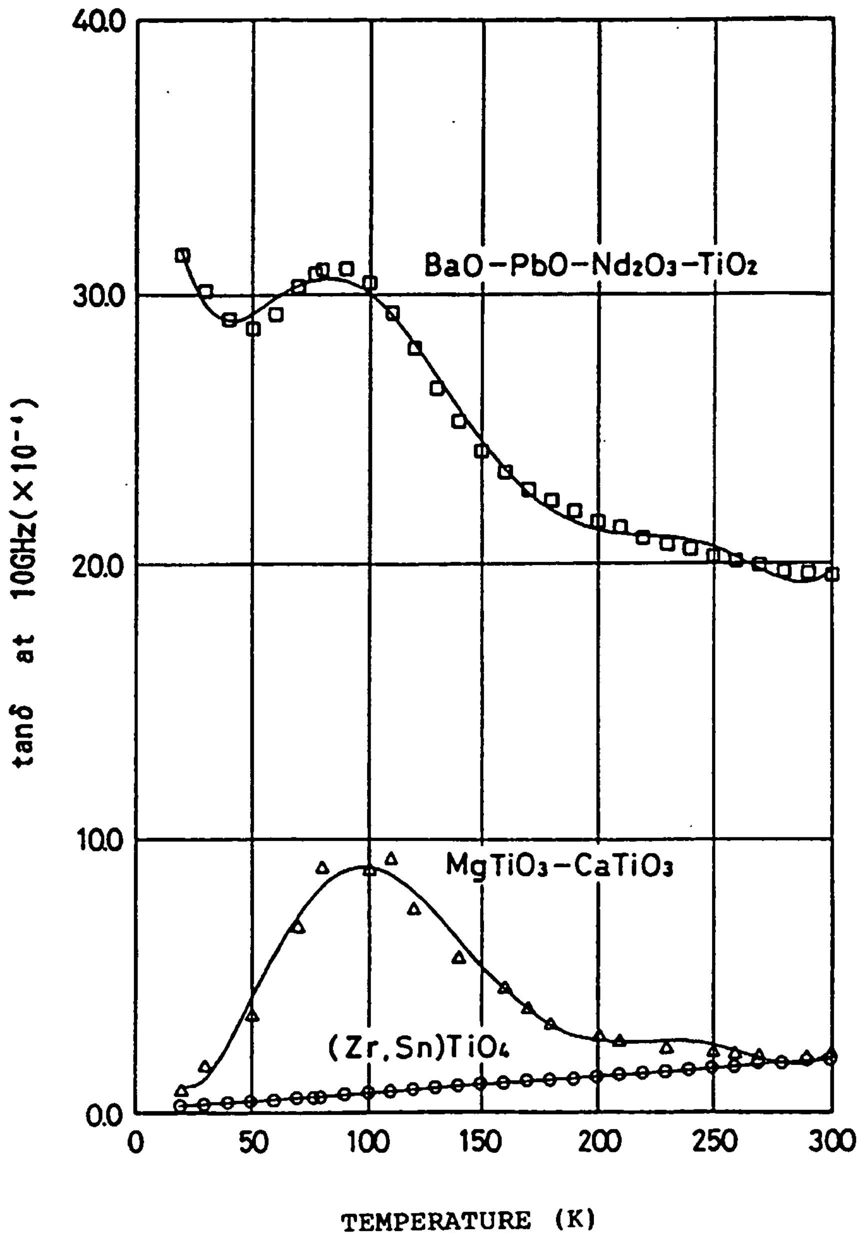
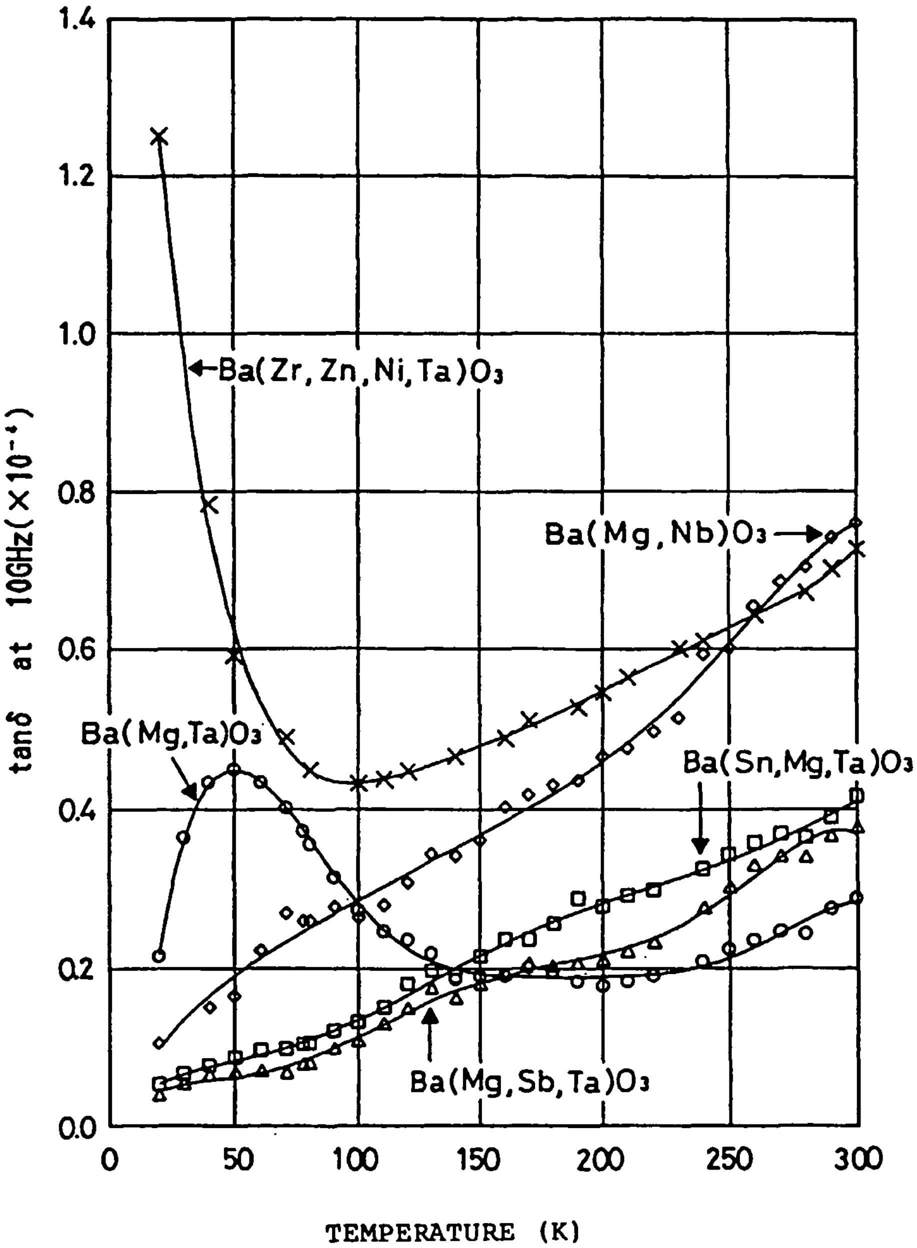

40.0
30.0
20.0
10.0
0.0
tanδ at 10GHz(×10⁻⁴)
BaO-PbO-Nd2O3-TiO2
MgTiO3-CaTiO3
(Zr,Sn)TiO4
0
50
100
150
200
250
300
TEMPERATURE (K)

Fig. 7


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
TEMPERATURE (K)
tanδ at 10GHz(×10⁻⁴)
Ba(Zr, Zn, Ni, Ta)O3
Ba(Mg, Nb)O3
Ba(Mg,Ta)O3
Ba(Sn,Mg,Ta)O3
Ba(Mg,Sb,Ta)O3